DESIGN AND ANALYSIS OF THE TEST SECTION FOR AN OPEN CHANNEL FLUME

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ABSTRACT

The needs of renewable energy is now in urgency as the source of the fossil energy is depleting from day to day. This study will focus on the potential energy extraction from the river flow to generate electricity and aiming is to design and analyze the test section for an open channel flume. The objective of the study is to design and analyze the test section for an open channel flume. Five concept designs for a flume were constructed and Flow Simulation Package was used to simulate the flow condition in the developed models. Result indicated that there is a significant difference across the test section between all the five designs in terms of pressure drop, velocity, turbulence intensity, as well as the velocity profile pattern. Based on the investigation, the best result derived from Design 5 which has been resulted in the average velocity of 3.36 m/s in the test section, average total pressure of 1172.5 kPa with the pressure drop of 6.56 kPa, and average turbulence intensity of 21.15%. Velocity profile gave a normal pattern and in agreement with the principal of zero-slip condition. These finding led to the conclusion that Design 5 configuration gave the best quality of flow condition and properties in the test section compared to the other four designs based on the analysis result.

ABSTRAK

Keperluan kepada sumber tenaga yang boleh diperbaharui adalah satu agenda utama masa kini memandangkan sumber tenaga semulajadi sebagai sumber tenaga utama semakin menurun dari hari ke hari. Kajian ini akan bertumpu kepada pengekstrakan tenaga keupayaan daripada aliran air sungai untuk menjana tenaga elektrik dan sasaran kajian adalah untuk mereka dan menganalisis kawasan ujian bagi saluran air terbuka. Lima rekabentuk telah direka dan pakej Solidworks Flow Simulation telah digunakan bagi tujuan analisis. Keputusan kajian menunjukkan terdapat perbezaan signifikan di dalam kawasan ujian saluran air terbuka kelima lima rekaan saluran air terbuka. Perbezaan ini diambil kira berdasarkan jatuhan tekanan, halaju air yang mengalir, kecenderungaan kekacauan aliran air dan juga corak profil halaju air. Daripada simulasi dan kajian yang dijalankan , Rekaan Konsep ke 5 telah menunjukkan hasil kajian yang terbaik. Rekaan Konsep ke 5 telah menghasilkan halaju purata aliran air sebanyak 3.36 m/s, purata tekanan sebanyak 1172.5 kPa dengan jatuhan tekanan sebanyak 6.56 kPa dan purata kecenderungan kekacauan air sebanyak 21.15 %. Corak profil halaju air yang dihasilkan pula adalah normal yang mana bertepatan dengan prinsip bendalir yang mana halaju air akan bertambah seiring dengan ketinggian aliran air menuju permukaan air. Penemun ini mendorong kepada kesimpulan bahawa Rekaan Konsep ke 5 memberi keputusan kualiti keadan aliran air yang terbaik dibandingkan dengan empat rekaan yang lain berdasarkan keputusan analisis.

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LIST OF SYMBOLS

A	Area
Fr	Froude Number
Re	Reynolds Number
v	Velocity
ṁ	Mass flow rate
η	Efficiency
ρ	Density
Rh	Hydraulic radius
P	Perimeter
ν	Kinematic viscosity
L	Characteristic Linear Dimension
g	Gravitational Force
s	Slope
n	the Gauckler – Manning coefficient, unitless
μ	Dynamic viscosity of the fluid
k	conversion factor of length

LIST OF ABBREVIATIONS

CAD	Computer Aided Design
CFD	Computational Fluid Dynamics
2D	2 Dimensions
3D	3 Dimensions
DID	Department of Irrigation and Drainage

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter explains about overview of renewable energy focussing on tidal energy at Pahang River specifically, the problem statement, objectives and the scopes of the project.

1.2 OVERVIEW OF ENERGY EXTRACTION FROM TIDAL ENERGY

The developing world nowadays is having a high demand on energy supplies, which is highly needed for the support of people needs, industries, utilities and daily needs. The high demand is causing the whole world to be burdened up to fulfil this demand. Due to the needs, energy source which is highly depending on the fossil fuel is highly used nowadays. The world is suffering of supplying this energy source.

The supplies are being dug and being used daily. Due to less utilizing of renewable energy source, the fossil fuel we have today is keeping depleting fast. This may be caused by the less awareness of utilizing the renewable energy which may be existed in the form of wind energy, sun ray energy and tidal energy. This may be supported by the ability support facilities in applying the renewable energy source and practicing it in the real world condition.

1.3 TIDAL ENERGY TESTING FACILITY

Facilities to supports the application of renewable energy to then be applied in the real world should be developed. This is to prevent the existing energy sources to be depleting fast and as a replacement to the existing energy sources once they are all gone in the future. The reality is, the world is keeping developing from day to day, and energy sources will be more crucial.

The problem which the nation is facing currently is the initiative to introduce the usage of renewable energy to the citizens. One of the factor that restraint the idea is less exposure given and less infrastructure to support the usage of renewable energy and to support the research to discover new findings.

One of the most well known and popular type of renewable energy source is hydro power energy. It is known as the cleanest renewable energy type and less destruction to environment caused by. For this reason, the foundations for the renewable energy to be used have to be developed for a better nation and for a better living of future generation.

1.4 PROBLEM STATEMENT

One of the reasons that block the development of the hydro renewable energy is the lack of testing facilities to conduct tests for hydro turbines or micro hydro turbines. The testing apparatus to evaluate the river flow which may show variability of river properties such as river velocity, mass flow rate and volume flow rate are limited.

The open channel flume is an important infrastructure to test the ability of a micro hydro turbine. In the open channel flume, there is a test section area where hydro turbines will be located and where the flow of the water is the most optimized in the overall length of the open channel flume.

1.5 OBJECTIVES

The test section is the location where the model will be placed for testing. The test section is where flow properties in the channel must be optimized. To achieve that, the objectives of the study will be:

a. To analyze the design configurations effect to the flow in the different open channel flume designs.
b. To determine the average velocity of water flow in every designs.
c. To determine the total pressure by the water flow in every designs.
d. To determine the turbulence intensity in the water flow in every designs.
e. To determine the pattern of velocity profile in the water flow.

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1.6 SCOPE OF PROJECT

In order to achieve the objectives as mentioned, the scopes of this study are defined as below:

a. The study is to analyze the different types of configurations of open channel flume.
b. Properties of the water in the open channel flume must be aligned with and approximate with the tidal stream current of Sungai Pahang.
c. Solidworks and Solidworks Flow Simulation will be used to draw and analyze the designs of the open channel flume.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will be giving an overview of flume , the properties of river and the theories to support the establishment of a water channel.

2.2 FLUME

Flume is an artificial water channel in the form of gravity chute that leads water from an inlet to an outlet and circulate the flow (Fred, 2013). A flume water channel direct water from water source to specified destination. The history of a flume was, at first a flume is structured elevated wooden box that will follow the geographical condition of the earth. These method of directing the water from its source have been used widely in the mining industries to deposits useful mineral such as gold, tin and other heavy minerals. In the other cases, in the early years of flume creation, flumes were used to transport logs in the logging industry, to generate electric power and to power various waterwheels. An early design of flume can be observed in Figure 2.1.

Figure 2.1: Early Design of Wooden Box Flume

Source : Armfield United Kingdom (2011)

In the modern years and ages, flumes were optimized for various applications. The examples of flumes widely used today are Venturi Flumes and Parshall Flumes. The two examples named are used to evaluate the flow rate of water (or other liquid).

The flume studied and designed in the scope of the project is flumes designed for flow rate evaluation. The flume will be consisting of a water channel which will be consists of the main test section of water in it. The other components which will be completing a flume are water pumps, convergent inlet, divergent outlet, pumps, water reservoirs and piping system. This complete combination of a flume will be important in simulating the real condition of water in river. To design and establish a flume, the properties of a flume is very important. This will be involving the width of the flume, the length of the flume, material used, the specified depth, and the pump specification used. This will be affecting the properties of water such as the volume flow rate of water, mass flow rate of water, Froude number of water, Reynolds number of water and velocity of water. The listed affecting parameters are very important in simulating the real condition of the real water properties in the river. The flow condition may not be the same, but at least will be almost the same with the study case.

Parallel with the objectives of the project, the flume will be used of testing the apparatus or machines for the real objectives of flumes being constructed which is as a testing utility to evaluate and test the potential of hydro turbines and micro hydro turbines to generate electricity. The hydro turbine will be located in the water channel effective location which is having effective length from all over length of the water channel (called the test section) and at an effective depth. From specified properties of water flow that is suitable with the flow of the river, the hydro turbine will be tested. The result obtained from the test, will be depicting almost the real result in the real condition of the river. This will be making the testing process of useful apparatus made easy.

2.3 OPEN CHANNEL FLOW

Open channel flow will be describing the flow of water in a channel that is open to the atmosphere. An open channel will be involving just liquids normally water or wastewater which expose to the gas usually at the atmospheric pressure. Figure 2.2 is showing the open channel for water flow manufactured by Armfield, United Kingdom.

Figure 2.2: Open Channel Water Flow

Source : Armfield United Kingdom (2011)

There are slight differences between flows in pipes to be compared to the flow in open channels. Flow in pipes will be driven by gravity and pressure differences, while flow in open channels will be driven naturally by gravity. Water flow in river, which depicts flow in open channel is driven by the difference in level which is elevations of upstream and downstream of the river. That will be the same in the flow of open channels. Gravity and friction will be affecting and driven the flow in the open channels. They establish the flow rate in open channel. The height of the free surface along the channel from the bottom of the channel will change along with average flow velocity. The velocity drops in the flow could occur if there is any external component in the water channel. According to Yunus and John (2006), the fluid flow in typical piping or channel passes through the components such as various fittings, valves, bends elbows and contractions in addition to the straight section of piping or channel will interrupt the smooth flow of the fluid

In an open channel, the velocity at the surface will be zero at the bottom surface and the side of the channel due to the no slip condition. Open channel flows are divided into two types that are steady and unsteady flow. A steady flow is a flow that has no change with time at given location. To represent this, we will be referring to the depth of flow. Depth of flow will be changing and vary all along the channel. The flow is said to be steady if the depth of flow does not change with time at any given location (Yunus & John, 2006).

Backflow could occur in the water channel. Backflow usually occurs in the outlet region where the movement of the water meets other external equipment such as water convergent which acting as a dam to control the depth of the water in the channel. According to Luna (1953), putting in the dam created backflow and the dam can be determined as the control section. The depth at this section will be the critical depth and the critical depth can be calculated from discharge, Q. The height of the energy line is determined from the line of critical depth.

The pressure distribution of water in the open channel could also differ and fluctuates from one location to another. According to Chow (1959), in contrast to pipe flows, open channel flows are characterized by a free surface which is exposed to the atmosphere. The pressure on this boundary thus remains approximately constant irrespective of any changes in water depth and flow velocity

The flows in the channel are composed of variety of types of flows. According to Gregory (1993), the flow in the channel was composed of multi velocity of flow. Some of the flow was composed of high velocity high turbulence conditions in the centre core of flow, moderate velocity and high turbulence conditions on the side of the channels under study. Thus, the flow will have tendencies to have turbulence in the flow along the channel.

2.4 FLUME TEST SECTION

A test section is where the test device is going to be located (turbines, micro turbines) which having uniform flow.

The water channel is divided into three sections, which are the entry section, the test section and the exit section. The length of these three sections will be equally divided from the whole length of the water channel. The test section where turbines, or micro hydro turbines to be located is going to be the very middle point of the water channel. The flow in the location is the most optimized of all.

2.5 TEST SECTION CONDITION

The test section is the most important and the most critical part in the structure of a flume. This is where the test of the hydro turbine or any other energy generating apparatus will be conducted. The dimension and specification will be affecting the whole water properties in the whole flume structure. The height, width and length will be affecting other result of water mechanics such as Froude number, Reynolds number, mass flow rate of the water, volume flow rate and as well as water velocity. This will be in conjunction with the surface roughness of the materials used in making the inner surface of the water channel.

The water channel length itself should be long enough. In parallel, this will allow the test section to be long enough as well. In constructing the test section, some other consideration should be taken into account. This will be including the thickness of boundary layer, the condition of flow at the inlet of the water channel including of its length and the condition of the flow at the outlet of the flow at the outlet, instead of the ideal width and depth of flow in the water channel. All listed factor will be affecting of the effective useful flow cross section that will be important to move the propeller of the hydro turbine at desired velocity flow, similar to the river flow. The test section should be long enough so that the simulation of flow filed in interest can be allowed (Arthur & Peters, 1987). To gain the most effective length for testing in the test section for the test purposes, the length of the water channel itself should be long enough and the length of the efficient test section will be resulted of ten times the width of the water channel (Shoitiro, 2007).

The depth of test section area will also affecting the flow properties. In deciding the effective depth, there are few points to be considered. That will be the hydraulic radius that will be affecting the Reynolds number as well. From the technical aspect, the size of the hydraulic turbine should be taken into account. This will be much related to the objective of the project, and how much power will be targeted as the output from this project. From the objective of the project, we will be able to decide the size of the turbine to be used, and the size of propeller to be used for the future project. The most effective depth is 25% of the flow depth from free surface (Yunus & John, 2010)

Also by Yunus and John (2010), the flow velocity is zero at the side and bottom surface because of the no –slip condition and maximum at the mid plane for symmetric geometries. The no- slip condition on the channel walls gives rise to velocity gradients, and wall shear stress develops along the wetted surfaces. This will affect the condition and the potential of energy in the test section area.

2.6 REYNOLDS NUMBER SELECTION

Ratio of inertial forces to viscous forces in the fluid will be defined as Reynolds Number. Reynolds number is a dimensionless quantity. The inertial forces are proportional to the fluid density and the square of the fluid density at large Reynolds number. At small Reynolds number, the viscous forces are in large quantity to suppress the fluctuations and to keep the fluid constant.

In selecting the suitable flow for the flume in the test section, the selection of the Reynolds number would be very important. The Froude number will be affecting the type of flow, and how is the ability of the flow to move the propeller of the turbine by the force exerted on it by the flow. Most flows of concern have boundary layer Reynolds Number Greater that 10^5. low Reynolds number would cause numerous problems and provide challenging design problem (Arthur & Peters, 1987).

2.7 FROUDE NUMBER SELECTION

One of the important parameter that governs the character of the flow in open channel is Froude (Fr) number. The flow will be characterized by:

Fr < 1 Subcritical flow

Fr = 1 Critical flow

Fr > 1 Supercritical rapid flow

The Froude number is expressed as the ratio of the flow speed to the wave speed. The Froude number can be also be expressed as the square root of the ratio of inertia force to gravity force.

The Froude number is having the same role as the Reynolds number. The Froude number has to be in the subcritical condition and not in the supercritical condition or critical condition. The Froude number should be in the correct range and it is a compromise (Arthur & Peters, 1987).

Parameters such as Froude Number and Reynolds Number are very important in the calculation of determining the thickness of the velocity profile. This will help to decide the best hydraulic radius and wetted perimeter for the water channel. The useful cross sectional area in the water channel will be determining the efficiency of energy extraction in the water channel.

2.8 SPEED OF SURFACE WAVES

In open channel flow, surface waves can be very high. The surface waves may be very smooth or break on the surface. Wave speed is an important factor in the flow of water in open channel flow. Surface waves are the speed at which a surface disturbance travels through the liquid. In a long and wide open channel, that initially contains a still liquid at certain height. One end move with certain speed , will generate a surface wave at certain height. This wave with specified height will propagate a surface wave into the still liquid.

The wave speed can also be determined by using the energy balance equation. The concentric waves in rectangular hydraulic radius will propagate evenly in all directions and vanish in some distance. The surface waves will be affecting much on the subcritical or supercritical properties of the water flow. The surface waves may cause the water level to drop to rise or drop, depending on whether the flow is subcritical or supercritical. In conjunction with this water flow property, the liquid level may drops gradually in flow direction and may be rise up, in the subcritical flow or supercritical flow (Yunus & John, 2010).

The surface waves will be affecting the velocity profile of the fluid flow. Surface area will be affecting the velocity on different location in a certain length of the open channel and also the static and dynamic pressure in locations along the length of the channel and most importantly the condition in the test section area. This will be affecting the data reading pattern of the velocity and the total pressure reading.

2.9 SPECIFIC ENERGY

The sum of pressure and dynamic heads of a liquid in an open channel is called the specific energy, E. Specific energy is the sum of mechanical energy of a fluid in terms of heads which then becomes the sum of the pressure and dynamic heads. Specific energy shows the variation of specific energy with flow depth.
(Yunus & John, 2010).

The point of minimum specific energy is the critical point and the flow become critical when the specific energy comes to its minimum value. This shows that the flow is subcritical at lower flow velocities and higher flow depths, supercritical at higher velocities and thus lower flow depths and will be critical at the critical point.

In the open channel, the flow depth, flow velocity and specific energy remain constant in the uniform flow. Uniform flow will cause the specific energy to increase or decrease which will be depending on the slope of the channel and frictional losses. This is an important tool in investigating the properties of varied flow. Specific energy will help to understand the varieties of reading pattern in the test section area of the water channel.